

# SCIENCE FOR GLASS PRODUCTION

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## PHYSICAL-CHEMICAL INTERACTIONS DURING CONTACT BETWEEN MOLTEN GLASS AND REFRACTORIES

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The physical-chemical interactions at contact of molten glass with refractories in a glassmaking furnace, mostly electricity melted baddeleyite – corundum (bacor), are examined. Three basic interactions are discussed: surface phenomena, chemical interactions, and transport phenomena.

**Key words:** molten glass, refractories, surface phenomena, chemical interactions, transport phenomena.

Glassmaking and the preparation of molten glass for molding are conducted in refractory tanks and feeders. High temperatures and complicated physical-chemical interactions in the contact zone destroy the refractory masonry and result in the appearance of different types of flaws on the molded glass articles.

In what follows the interaction of glass melts, having the most common compositions (sheet glass, glass containers), with baddeleyite-corundum (bacor) refractory melting tank of a glassmaking furnace is examined.

The characteristic features of the contact phases are:

- the glass melt at high temperatures is a chemically active ionized liquid with high viscosity and surface tension, exhibiting nonuniformity of the composition, properties, and structure;
- the structure of the refractory materials is represented by microparticles of the crystalline phase, cemented by a refractory glassy phase; the rough surface of refractories has the capability of adsorbing various compounds from gases, vapors, and liquids; as a result of the nonuniformity of the composition, properties, and structure of the refractory materials, they breakdown nonuniformly in a glassmaking furnace.

The interaction of the molten glass with the refractories of a glassmaking tank determines the service life of the glassmaking furnace and the quality of the glass. This is mainly due to the quality of the refractory materials but the

character of the interaction is determined by complicated complex processes occurring at the interphase boundary, including:

- chemical interaction;
- surface phenomena;
- transport phenomena.

These processes result in the formation of a “meso-layer” with thickness  $\sim 10^{-3}$  m. Marked surface, chemical, and ionic-diffusion phenomena are observed in the direct contact zone (thickness  $\sim 10^{-5}$  m). As the thickness of the “meso-layer” increases, the convective components of the transport phenomena begin to manifest together with shearing deformations.

Ordinarily, works devoted to the corrosion of refractory materials examine the overall interaction picture, which is associated with the glass stability of refractories of the glass-making furnaces. Individual components of the interaction of refractories and the molten glass have also been studied. The key information on these directions is contained in [1 – 6].

### CHEMICAL INTERACTIONS

The tanks of glassmaking furnaces are constructed from baddeleyite (bacor) refractory beams. The chemical composition of bacor is close to the eutectic region of the ternary system  $\text{Al}_2\text{O}_3 - \text{ZrO}_2 - \text{SiO}_2$  [7] (Fig. 1). The structure of bacor is characterized by aggregate concretions of baddeleyite and corundum crystals, which largely determine the resistance of refractories to glass melts. However, when melted refractories are prepared the phase correspondence to equi-

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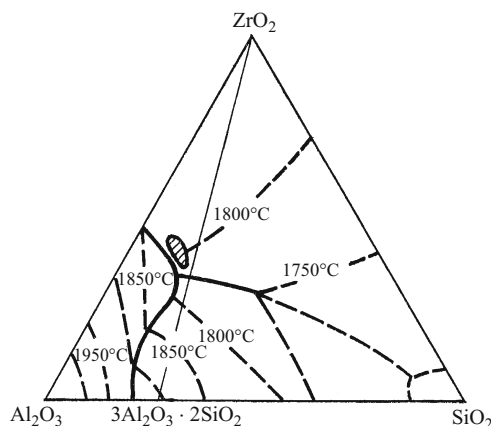


Fig. 1. Field of bacor refractory application at the ternary diagram  $\text{Al}_2\text{O}_3 - \text{ZrO}_2 - \text{SiO}_2$  (▨).

librium states in the above-mentioned ternary system is incomplete; this is manifested as incomplete crystallization and phase separation of the aluminum, zirconium, and silicon oxides. Specifically, crystallization of some amount of corundum not bound in aggregated concretions with baddeleyite is observed. As a result of the incomplete crystallization the structure of the refractory contains 10–15%<sup>3</sup> relatively low-melting glass phase which contains up to 50%  $\text{SiO}_2$ , 25–30%  $\text{Al}_2\text{O}_3$ , 5–7%  $\text{ZrO}_2$ , 2.5–3%  $\text{CaO}$ , and 5.5–7% alkali oxides; partial microcast mineral formation is observed. Petrographic, x-ray phase, and electron-microscopic studies reveal in the glass phase mullite bacor, tetragonal zirconium oxide, and baddeleyite. The  $\text{Al}_2\text{O}_3$  content in the glass phase is much higher than its content corresponding to the stoichiometric state of alkali aluminosilicates. This creates conditions for the interaction of excess  $\text{Al}^{3+}$  ions with  $\text{Na}^+$  ions (diffusing in the glass phase from the contact melt), redistribution of the oxygen ions and the formation of alkali aluminosilicates.

All chemical processes between the constituent parts of bacor and the molten glass differ with respect to the composition of the refractory and the melt, including components which have different mobility and capability to enter into chemical reactions. This difference of the acid-base characteristics of contact media increases with increasing temperature. High-temperature processes directed toward establishing more equilibrium states in bacor activate some corrosion processes. Thus, the interaction of corundum with silica prepares the subsequent formation of alkali aluminosilicates.

The main chemical interaction of the molten glass with the refractories is the action of the alkali and alkali-earth ions on the structure of the refractory. Alkali ions are most active. The penetration of these ions into the surface layer of the refractory occurs along the glass phase first. As a result its viscosity decreases, the interaction of the excess  $\text{Al}_2\text{O}_3$  of the glass phase with the alkali atoms and the dissolution of the

mineral phases of the refractory, first and foremost, corundum, is not related with the aggregate concretions with baddeleyite. In the process the cohesiveness of the general structure of the refractory breaks down, which assists in the gradual separation of the recrystallized fine-grain baddeleyite.

The phase separation of the oxide components of bacor mainly predetermines the chemism of its breakdown and the character of the contact mineral formation. The constituent parts of the refractory, which differ strongly with respect to their resistance to the molten glass, break down differently. As a result, the corrosion of the refractories can be represented chemically as a series of independence processes, for each of which there is a physical-chemical model in the form of the corresponding phase diagrams [7]. For baddeleyite such a model is the system  $\text{Na}_2\text{O} - \text{ZrO}_2 - \text{SiO}_2$ , showing the enhanced chemical resistant of baddeleyite to the molten glass and the predominant possibility of existing for a quite long time in melts of commercial silicate glasses. For corundum the phase diagram of the state  $\text{Na}_2\text{O} - \text{Al}_2\text{O}_3 - \text{SiO}_2$  attests to quite wide possibilities of chemical interaction with separation of alkali aluminosilicates ( $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot n\text{SiO}_2$ ), primarily such as nepheline and carnegieite ( $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ ).

Thus two directions of the main reactions are possible in the contact zone of the molten glass and the bacor refractories:

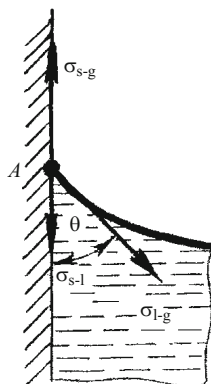


The rate of the interaction according to the reaction (2) is much higher than that for the reaction (1). In this connection, nepheline and carnegieite crystals form in the glass of the contact zone under certain conditions; the presence of these crystals together with baddeleyite and tetragonal  $\text{ZrO}_2$  crystals is observed in complex studies of contact-zone glass.

At the same time a number of studies have shown that sodium-zirconium silicates, predominately  $\text{Na}_2\text{O} \cdot \text{ZrO}_2 \cdot \text{SiO}_2$ , can form. However, according to the data of [8] such mineral formations as flaws in glass are observed quite rarely, since they are characteristic for substantially more basic silicate glasses and, differing by limited regions of stability, cannot be sufficiently stable in melts of commercial glasses for the production of the most massive types of articles, since these compositions have an elevated content of silica with a comparatively low content of  $\text{Na}_2\text{O}$ .

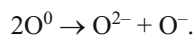
The differential character of the chemism of the breakdown of bacor weakens its phase-structural bonds, for example, such important ones as mineral concretions of baddeleyite and corundum or a binding (cementing) glass phase. In this case the chemical interaction facilitates breakdown right up to the point where in a number of cases it is not individual minerals or the products of their transformation but rather small fragments of the refractory that appear in the molten glass.

<sup>3</sup> Here and below — content by weight.



**Fig. 2.** Surface (interphase) tension at glass – refractory contact:  $\sigma_{s-g}$ ) surface tension at the gas – refractory boundary;  $\sigma_{s-l}$ ) interphase tension at the refractory – melt boundary;  $\sigma_{l-g}$ ) surface tension at the melt – gas boundary;  $\theta$ ) wetting angle.

As a result of chemical interaction and dissolution of the components of the refractory in the glass melt, the crystal lattice of baddeleyite and corundum breaks down. In the process  $Al^{3+}$  ions form, and substantially fewer  $Zr^{4+}$  and oxygen ions form; in addition, for oxygen the bridge ions transform into free non-bridge ions:



Entering the glass melt these ions participate in the formation of coordination polyhedra together with aluminum and zirconium ions. In the process conditions for equilibrium of oxygen ions in the glass melt ( $O^0 + O^{2-} \leftrightarrow 2O^-$ ) change, and conditions for attaining saturation concentrations for the ions  $Al^{3+}$ ,  $Zr^{4+}$  of the contact layer and their diffusion into the melt of the prescribed composition of the glass are created.

The chemical contact interaction, especially, at the surface level of the molten glass, intensifies considerably in the region of the hopper since low-viscosity silicate melts with an elevated content of the active alkali and alkali-earth ions come into contact with the refractories.

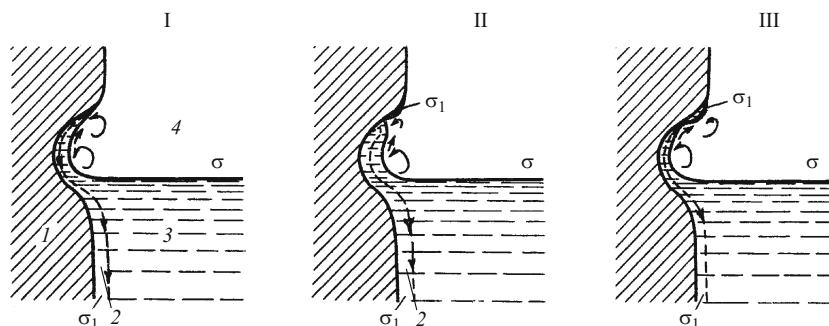
## SURFACE PHENOMENA

Surface phenomena play an important role in the breakdown of the refractories in glassmaking furnaces. We shall examine this for corrosion at the surface level of the molten glass and for vertical cellular corrosion.

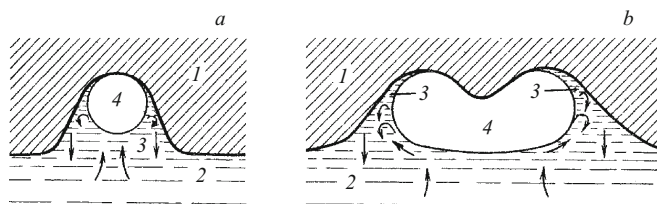
### Corrosion of Refractories of the Melting Tank of a Glassmaking Furnace at the Level of the Molten Glass

**Surface.** In this location the wall beams of the tank of a glassmaking furnace are subjected to the greatest damage. Here the physical-chemical interactions occur at the boundary of the three phases (molten glass – refractory – gaseous medium). The model studies using solutions and crystals as well as a study of the character of the breakdown of the refractories when they come into contact with the molten glass taking account of the time factor [9 – 11] showed that interphase-gravity convection with participation of surface forces occurs at the interphase boundaries.

The refractories of the glassmaking tank, which have a nonuniform surface, are well laved by the chemically active molten glass, as a result of which a concave meniscus forms under the action of the surface forces (Fig. 2). At the same time the alkali ions  $Na^+$  interact chemically with the components of the refractory on its surface. Since the surface of the refractory is nonuniform with respect to the chemical composition and structure, the interaction initially occurs at the weakest sites (glass phase). The glass phase becomes enriched with  $Na^+$  ions and its viscosity and cementing power decrease; the crystal lattice breaks down and the corundum and baddeleyite dissolve partially. A thin diffusion layer with high viscosity is formed; this layer has a wavy outer surface because of the nonuniformity of the interaction. The transition of the  $Al^{3+}$  and  $Zr^{4+}$  ions into the diffusion layer increases its thickness and density. The increase of the interphase boundary of the diffusion layer and the action of gravity on the outer boundary of the diffusion layer promotes the formation of an interphase-gravity convection cycle. The outer part of this layer moves downward under gravity, smoothing the interphase surface and creating nonuniformities, from which striae are formed under the action of local and global convection flows. Chemical interaction, surface tension, interphase-gravity convection, and diffusion together form a recess along the perimeter of the top wall beams of the tank at the level of the surface of the molten glass. Small but unavoidable oscillations of the level of the molten glass change the position of the contact boundary of the three phases, expand the region of corrosion and result in the formation of a slit-like groove along the perimeter of the refractory masonry. A diagram of the corrosion of a refractory at the level of the surface of the molten glass with a recess is presented in Fig. 3.



**Fig. 3.** Diagram of the corrosion of refractories at the level of the surface of the molten glass in the glass-making furnace: I, II, III) positions of the sequences of the process; 1) refractory; 2) contact (diffusion) layer; 3) molten glass; 4) gas medium;  $\sigma$ ) surface tension of the molten glass of the main composition;  $\sigma_1$ ) surface tension of the melt of the diffusion layer.



**Fig. 4.** Diagram of vertical cellular corrosion under the action of small (a) and large (b) bubbles on the refractories: 1) refractory; 2) molten glass; 3) zone of formation of the diffusion layer and interphase-gravity convection; 4) bubbles.

As noted above, a highly viscous diffusion layer with elevated surface tension forms on the boundary of the molten glass and the refractory (see Fig. 3, position I). On the one hand the "fresh" molten glass has a lower surface tension and, flowing along the outer surface of the diffusion layer, rises upward and at the same time strives to decrease the surface area (solid arrows). On the other hand an interphase-gravity convection cycle (dashed arrows) starts to form. Next (position II), the molten glass rises to a height at which the surface forces balance gravity. At the same time the top part of the raised molten glass strives, under surface forces, to shrink and assumes a rounded shape. In the process the thickness of the layer increases somewhat and the lowering of the molten glass in the outer layer under gravity intensifies. In addition, under surface tension a drop of high-viscosity molten glass starts to form at the edge the "lip." Next (position III) the thickness of the layers decreases and the process repeats. As the level of the molten glass rises, the rise height of the molten glass in the recess increases, the drop of molten glass on the edge of the "lip" grows; when the force of gravity is greater than the surface tension forces, the drop detaches from the "lip" and, falling into the molten glass, serves as a source of striae.

**Vertical Cellular Corrosion.** This form of the corrosion of the refractories pertains predominantly to the lower surfaces of the wall beams of the tank of the glassmaking furnace (in the presence of horizontal and seams which are not tight enough) and cover beams of the flow channels and is due to gas bubbles. In the foreign literature it is designated by the terms *upward drilling* (English) — vertically rising drilling — and *blasenbohren* (German) — drilling by a bubble. The model studies performed using solutions and crystals in combination with a study of the character of the breakdown of the refractories [12, 13] showed that surface phenomena play a decisive role in this case also. A diagram of the vertical cellular corrosion of the refractories is presented in Fig. 4.

For small gas bubbles vertical cellular corrosion starts at the moment a bubble enters a crack, chip out, or recess which are formed as a result of the initial complex action of the molten glass on the nonuniform surface of a refractory (Fig. 4a). In the process of chemical interaction of molten glass with a refractory and in the presence of local variations

of the surface tension, conditions are created on the surface of a bubble for interphase convection with participation of surface forces. The products of breakdown of the refractory move along the interphase surface, thereby causing the bubble to rotate. This rotation decreases the thickness of the boundary diffusion layer with relatively high surface tension, simultaneously delivering to the contact zone fresh molten glass with high content of alkali ions and relatively low surface tension. Such motions of a bubble and flow of the molten glass, which are due to the gradients of the surface tension, lead to a quite high rate of vertical cellular corrosion of refractory beams of the tank of a glassmaking furnace, which have bottom horizontal surfaces. Aside from rotation the bubbles periodically undergo vertical down-up motion under the influence of the interphase-gravity convection and surface forces.

Figure 4b shows the character of the vertical cellular corrosion in the case of large gas bubbles. A large bubble, which has a quite strong buoyancy force, flattens; in the process the central contact zone of the bubble with the refractory is subjected to an elevated pressure, and in this zone interphase-gravity convection is greatly impeded. Actually, this convection under a surface tension gradient occurs only in regions of lateral spherical ends of the flattened bubble. Thus a kind of protective zone with a lower corrosion rate is created in the central part of a flattened bubble. In time a bulge forms in this location, as shown in Fig. 4b.

## TRANSPORT PHENOMENA

It is well known that transport phenomena combine processes in which mass or energy transfer occur from some parts of a nonuniform material system to another. Ordinarily, it is assumed that the system consists of a single phase but its properties are nonuniform. The transport phenomena are similar to one another and are interrelated. There is also an analogy between the mechanisms of particle movement and the mechanism of momentum or impulse transfer, which determine the resistance, due to the magnitude of the viscosity, to particle motion.

Glass melts have definite structural particulars. As temperature increases, the complex silicon-oxygen framework  $[\text{Si}_m\text{O}_n]$  acquires elevated mobility and decomposes into diverse, very complicated ions with variable structure. The interrelation of the anions with the modifying cations becomes weaker; the latter acquire higher mobility as compared with the complex silicon-oxygen anions. Thus these anions, forming a three-dimensional framework, are decisive for the viscosity of glasses, and the more mobile cations are decisive for diffusion. Hence follows the conclusion that diffusion and viscosity are interrelated. This interrelation was first expressed by the Einstein — Stokes equation, which related the diffusion coefficient with the viscosity and the radius of the kinetic units. A number of studies established that the equation is inapplicable to high-viscosity glass-forming melts; the



relation between diffusion and viscosity can be expressed by the equation

$$D^m \eta = C,$$

where  $D$  is the diffusion coefficient;  $\eta$  is the viscosity;  $m$  and  $C$  are constant coefficients, and the coefficient  $m$  can be expressed as the ratio of the activation energies of viscous flow and diffusion:  $m = E_\eta / E_D$ .

Numerous experimental data confirm that the relation presented holds for various chemical compositions of glasses in a definite temperature interval. This relation also holds for temperatures at which molten glass interacts with refractories. It is precisely the high viscosity of molten glass and even higher viscosity of the products of its interaction with refractories that determine the quite low diffusion coefficients. These factors also determine the chemical interaction rate, since it is determined by the rate of the diffusion delivery of the chemically most active ions of the melt  $\text{Na}^+$  into the zone of reaction and removal of the products of the interaction from the reaction zone.

In [14, 15] the notions that diffusion and regions of diffusion interaction are zonal in character are developed in order to describe contact diffusion phenomena in low-viscosity liquids in low-viscosity liquids. These notions are also applicable for high-viscosity glassy melts in contact with the refractories of the tank of a glassmaking furnace. Three regions of diffusion interaction must be considered:

- region of rapid change of the concentration and occurrence of diffusion of ions directly near the interaction surface — *the diffusion layer*; here saturation concentrations are reached; this layer adjoins the surface of the refractory and from here the diffusing particles are transported into the volume of the melt by convective diffusion through the hydrodynamic boundary layer; the thickness of the diffusion layer is very small and can be determined approximately from the relation  $\delta_D = \delta / \text{Pr}_D^{1/3}$  ( $\delta$  — thickness of the hydrodynamic boundary layer;  $\text{Pr}_D$  is the Prandtl diffusion number); it follows from this relation that the thickness of the diffusion layer decreases substantially with increasing viscosity of the liquid;

- the region of constant distribution of the concentration and occurrence of convection diffusion at a definite distance from the interaction surface — *hydrodynamic boundary layer*, likewise having an elevated viscosity due to the comparatively active diffusion of ions which are formed as a result of the breakdown of the refractory; here laminar motion occurs and the viscosity of the melt plays the main role; for diffusion phenomena in fused glass which possesses a high viscosity relatively thick boundary layers are formed;

- the region where the concentration of the diffusing ions, especially for  $\text{Zr}^{4+}$ , is very insignificant compared with the saturation concentration; this is *the main volume of the melt*, where the motion of the molten glass is due to the process and convective flows; the viscosity of the molten glass

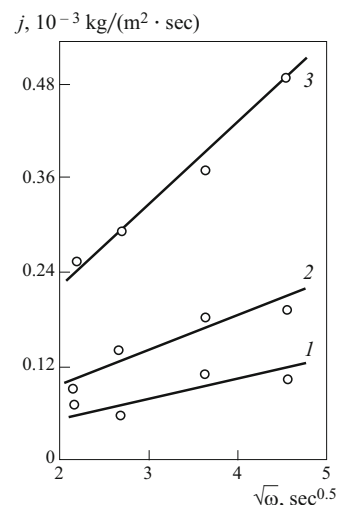


Fig. 5. Dissolution rate of refractory samples versus the angular rotation velocity: 1) bacor-41; 2) bacor-33; 3) corundum.

in the main volume of the melt is much lower than in the hydrodynamic boundary layer, which in combination with the concentration factors increases the diffusion rate.

Thus concentration diffusion is related with the viscosity and is zonal in character; the experimentally determined coefficients of diffusion will be average values of the diffusion coefficients in the regions mentioned.

The rotating disk method was used in experimental works to determine the corrosion resistance of bacor refractories as compared with the resistance of other types of refractories [14]. This method has been used before to determine the resistance of high-temperature oxides ( $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ ) in melts of metallurgical slags [16] and in electric melted corundum refractories in glass melts [17].

Figure 5 displays the experimental dependences of the rate of dissolution of disk-shaped objects on the angular rotation velocity at temperature  $1450^\circ\text{C}$ . The rectilinear dependence attests to a diffusion regime of dissolution of the refractory samples, i.e. the rate of dissolution is limited not by the rate of chemical interaction but rather by the removal of the products formed from the interaction zone. The rate of dissolution of the corundum refractories at the same temperature is presented for comparison. It is evident from the figure that the corrosion rate of bacor refractories is much higher at high temperatures. In this connection, corundum refractories should be used for the feeder pans in the glass forming machines, where the working temperature is  $150 - 200^\circ\text{C}$  lower than in the melting part of glassmaking furnaces. The comparatively low temperature in the feeders and the associated elevated viscosity of the molten glass lower the corrosiveness of the melt and the diffusion coefficient of the ions.

The authors of [18] studied the diffusion processes accompanying the interaction of electricity melted refractories with melts of commercial glasses. The dependences obtained enabled the authors to use the theory of zonal diffusion meta-

somatoses in contact-reaction natural formations to determine the corrosion of the refractory masonry of a glass-making furnace.

### CHARACTER OF THE CORROSION OF INDIVIDUAL ELEMENTS OF GLASSMAKING FURNACES

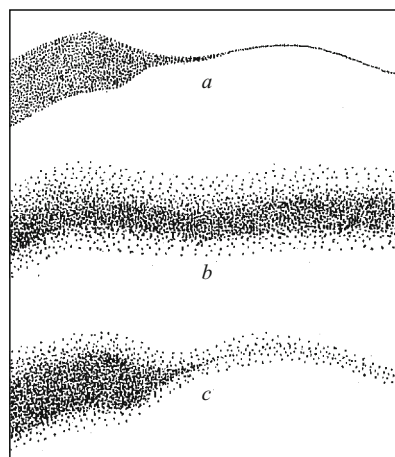
The interrelation of the physical-chemical interactions can be traced quite clearly in the corrosion of a number of elements of glassmaking furnaces [3, 19, 20].

When molten glass comes into contact with bacor refractories a diffusion layer is formed as a result of the chemical interaction, concentration gradients, and surface forces. It should also be noted that in the refractory – molten glass contact zone the portions of the molten glass enriched with  $\text{Al}_2\text{O}_3$  (and  $\text{ZrO}_2$  to a lesser extent) and depleted of  $\text{Na}_2\text{O}$  sink, and they are replaced with new portions of the molten glass with a lower content of  $\text{Al}_2\text{O}_3$  and no  $\text{ZrO}_2$  (interphase-gravity convection). In addition, deeper penetration of the  $\text{Na}^+$  ions along the glassy phase together with the formation of alkaline aluminosilicates promotes the separation of small structural blocks of the refractory, which contain aggregate concretions of baddeleyite and corundum crystals, and their removal from the contact zone. These blocks, which consist of baddeleyite and corundum crystals (stones), can become flaws in the finished article because of their very low solubility in the molten glass. During corrosion of the wall beams a lip is formed at the level of the surface of the molten glass, and drops of viscous molten glass enriched with  $\text{Al}_2\text{O}_3$  and  $\text{ZrO}_2$  drip from this lip. The bacor elements of the top structure of a glassmaking furnace can also become a source of such molten glass because of the “sweating out” of the glassy phase. Such molten glass contains up to 20%  $\text{Al}_2\text{O}_3$  and up to 6%  $\text{ZrO}_2$ , and it has elevated viscosity and surface tension; striae subsequently form from it.

Corrosion of the *wall beams at the level of the surface of the molten glass* is due to the high temperatures (active chemical interactions), surface phenomena at the boundary of three phases, ionic and convective diffusion transfer. Cooling of the top parts of the wall beams results in an increase of the viscosity of the molten glass in the contact zone of the three phases. Correspondingly, the rates of the chemical interactions and diffusion decrease.

The corrosion of the *top beams of the flow threshold* is due to a combination of high temperature in this zone (active chemical interactions) and comparatively high rates of motion of the molten glass (acceleration of diffusion processes). This pertains to the main process flow and convection flows, including interphase-gravity flows at the lateral surfaces. The intense motion of the molten glass intensifies the effect of convective diffusion because the thickness of the diffusion layer decreases.

The corrosion of the *cover beams of the channel* is due to high temperatures (chemical interaction) and rates of motion of the molten glass (intensification of diffusion processes) in



**Fig. 6.** Diagram of the action on striae in molten glass of: a) deformation under tensile forces; b) diffusion, and c) combined action of deformation and diffusion.

combination with vertical cellular corrosion (surface phenomena). The corrosion of the cover beams of the channel can be largely decreased by air cooling and tilting of the cover beams. The vertical cellular corrosion also develops on the bottom surface of the wall beams in the presence of horizontal and inadequately tight seams. This type of corrosion can be eliminated by use “palisade” beams, forming only vertical seams.

The corrosion of the main elements of the tank of glass-making furnaces leads to the appearance of flaws in the molten glass, predominantly in the form of stones and striae. The main types of flaws in commercial glass and methods of phase-structural diagnostics are indicated in [3, 8].

When molten glass interacts with bacor refractories conditions are created for the appearance of aluminozirconium striae with higher surface tension and viscosity than for the main mass of the glass melt in the tank of the glassmaking furnace. Such striae are homogenized with difficulty with the melt by their deformation and simultaneously occurring diffusion. A diagram of the stages of this process is shown in Fig. 6. Since the rate of diffusion in high-viscosity melts is low, the process of homogenization intensifies when the deformation stage intensifies, especially with forced mixing. In this case, because of the convective component diffusion processes accelerate somewhat, but they are strongly temperature and time dependent.

Recently, because of the intensification of the glass-making and formation processes in the production of glass containers as well as more stringent quality requirements for the final products there arose the problem of the appearance of fine aluminozirconium striae on the surface of the products; the striae are a consequence of the chemical interaction and interphase-gravity convection in the region of the contact layer at the boundary between the molten glass and refractory. Although the striae are not dangerous for the service characteristics of the products, it is often unacceptable

for users of glass containers. For this reason, methods are used to intensify the deformation and to redistribute the striae using a facility with propeller blade mixers in the feeder as well as by pouring off the heavier molten glass which has an elevated content of aluminum and zirconium oxides, through an opening at the bottom of the feeder [21].

Complex processes of contact physical-chemical interaction in the glassmaking furnaces are directly related with the technological processes in the production of refractory and glass articles. To increase the efficiency of glassmaking it is necessary to use in glassmaking works high-quality refractory parts and to distribute them rationally taking account of the structural features of the glassmaking furnace. In the process of furnace operation it is necessary to maintain optimal process regimes for glassmaking (temperature, specific volume of the molten glass, fuel burning regimes, mix and cullet loading, and others) and to monitor constantly the state of individual elements of the refractory masonry which are subjected to the greatest wear. This will make it possible to preserve high operating efficiency of the furnace during a long period of operation.

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